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Research article

Explaining people's perceptions of invasive alien species: A conceptual framework

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ABSTRACT

Human perceptions of nature and the environment are increasingly being recognised as important for environmental management and conservation. Understanding people's perceptions is crucial for understanding behaviour and developing effective management strategies to maintain, preserve and improve biodiversity, ecosystem services and human well-being. As an interdisciplinary team, we produced a synthesis of the key factors that influence people's perceptions of invasive alien species, and ordered them in a conceptual framework. In a context of considerable complexity and variation across time and space, we identified six broad-scale dimensions: (1) attributes of the individual perceiving the invasive alien species; (2) characteristics of the invasive alien species itself; (3) effects of the invasion (including negative and positive impacts, i.e. benefits and costs); (4) socio-cultural context; (5) landscape context; and (6) institutional and policy context. A number of underlying and facilitating aspects for each of these six overarching dimensions are also identified and discussed. Synthesising and understanding the main factors that influence people's perceptions is useful to guide future research, to facilitate dialogue and negotiation between actors, and to aid management and policy formulation and governance of invasive alien species. This can help to circumvent and mitigate conflicts, support prioritisation plans, improve stakeholder engagement platforms, and implement control measures.

1. Introduction

Social factors and processes are crucial for environmental management and conservation as humans are central in both shaping and responding to processes of environmental change

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(Bennett et al., 2017; Christie et al., 2017). Environmental managers and scientists who deal with social-ecological changes such as climate change, biological invasions, and land-use transformation are often frustrated with stakeholders who do not hold similar perceptions of what they believe constitutes appropriate management strategies or priorities; which can result in misunderstandings, inefficiency and sometimes conflict (Buijs et al., 2012; Woodford et al., 2016). Biological invasions, a major driver of environmental change, arise from purposeful or accidental human-mediated movement of species from their native ranges to new locations where they are alien (also referred to as exotic or non-native) (Richardson et al., 2000). A small proportion of these species spread extensively in their new ranges or become invasive (Richardson et al., 2000), often affecting biodiversity, ecosystem processes and human well-being (Pejchar and Mooney, 2009; Jeschke et al., 2014; Shackleton et al. 2019a; Pysek et al., 2012). Many constituencies, especially conservation practitioners and scientists regard the effects of invasive alien species (IAS) in a largely negative light and advocate for scientists and government institutions to research and manage them. However, a number of IAS, especially those introduced purposefully, may offer economic and intrinsic benefits, which can result in contentious issues and conflicts of interest surrounding their management, since some people may oppose certain forms or methods of control and want to derive benefits from the species (Olszańska et al., 2016; Crowley et al., 2017a; Vaz et al., 2017a; Zengeya et al., 2017; Bach et al., 2019; Villatoro et al., 2019).

Whether an individual or group of people regards an IAS as problematic, beneficial or do not mind either way, depends on a number of factors that influence their perceptions of the species and its effects (Kueffer, 2013). We focus here on human perceptions which, as defined by Schermerhorn et al. (2000), are processes "wherein people select, organise, interpret, retrieve and respond to the information from the world around them", producing mental impressions and constructions which will ultimately help shape behaviours and actions. Perceptions can be influenced by a number of social-ecological factors; therefore, the term 'perceptions' provides an interdisciplinary umbrella for other, more specific constructs that may be more solidly embedded in particular disciplines such as social psychology or sociology (Bennett, 2016). Here, we consider perceptions of IAS as held by individuals, but formed and reformed in interactions with a number of influencing factors and contexts (Robbins, 2004; Gobster, 2011; Kull et al., 2011; Rotherham and Lambert, 2011). These factors can include characteristics of individuals (e.g., knowledge, behaviour and social relationships) (see Fischer et al., 2011a,b; Shackleton and Shackleton, 2016; Nanayakkara et al., 2018; Potgieter et al., 2019), IAS ecology and biology (e.g., the density of the invasive species and its traits) (see Shackleton et al., 2007; García-Llorente et al., 2008; Robinson et al., 2017; Shrestha et al., 2019), economic influences (e.g., provision of financial benefits and/or costs) (see Shackleton et al., 2019a), and social influences (e.g., political contexts and human value systems) (Kull et al., 2011; Estévez et al., 2015; Bravo-Vargas et al., 2019; Wald et al., 2019).

Many studies examining perceptions of IAS consider only one or two influencing factors, lacking the development or discussion of more integrated and holistic understandings (but see Kueffer, 2013). For instance, Estévez et al. (2015) examined how individual human value systems shaped perceptions of invasive animals, while Novoa et al. (2017) focussed only on how species' traits and landscape factors influenced perceptions. One comprehensive study, focusing on Australian acacias in multiple regions of the world (Kull et al., 2011), highlighted three overarching factors: biophysical characteristics of the species, local environment and social context, and familiarity with the species. However, they studied one tree genus and, while the ideas may be applied to similar tree species (e.g., the genera *Eucalyptus, Pinus* or *Prosopis*), it is more difficult, less useful and probably misleading to extrapolate their insights to other invasive taxa such as mammals.

It is important for researchers and managers to build on these emerging understandings to progress towards a robust framework that can be adopted under various contexts, drawing on multiple disciplines, and serve as a diagnostic approach for understanding people's perceptions of IAS (Bennett, 2016; Bennett et al., 2017; Head, 2017). Taking a holistic view of the primary factors that shape perceptions will be beneficial for research, management, policy formulation, and governance. We present a consolidated conceptual framework to identify the key factors that influence human perceptions of IAS and to examine how they interact. An improved understanding can help mitigate conflicts of interest over IAS, facilitate prioritisation and decision-making, and make stakeholder engagement processes, collaboration and dialogue more effective through considering different knowledge systems (García-Llorente et al., 2008; Estévez et al., 2015; Turner et al., 2016; Bennett et al., 2017; Pagès et al. 2019; Shackleton et al., 2019b). The framework also enables us to highlight knowledge gaps and inform further research in this area, especially by improving understanding of the complexity of perceptions, and the role they play in promoting or hindering effective action and governance in response to IAS (Kueffer and Hirsch Hadorn, 2008; Courchamp et al., 2017). Our expectation is that this framework will enable perceptions to be considered more explicitly and proactively in management planning and research, rather than as a reactive response to emerging issues.

2. Methods

The conceptual framework was developed during a workshop with an interdisciplinary team of 16 people from 10 countries on five continents. We acknowledge the importance and uniqueness of the different approaches to understanding perceptions that are employed by diverse disciplines (Kueffer, 2013; Head, 2017; Vaz et al., 2017b). For example, ecologists have contributed to understanding how species' traits might result in different social-ecological effects, which in turn influence perceptions; psychologists have contributed frameworks and methodologies for understanding factors that facilitate perceptions on an individual level; sociologists and anthropologists aid in understanding perceptions that reflect, for example, cultural symbolism and patterns of interactions among individuals and groups; and historians and human geographers have improved understanding of how past processes and broader landscape contexts influence current perceptions. Consequently, we included participants from as many disciplines as possible, and specifically tried to link and complement disciplinary views. The workshop participants (the authors of this paper) included researchers in the field of social-ecological systems, ecologists, social scientists and historians, working on a broad range of different invasive animal and plant taxa in different regions of the world. Our joint work thus draws on relevant theories and concepts from multiple disciplines, such as the theory of planned behaviour, value-belief-norm theory and cognitive hierarchies from social and environmental psychology, invasion science theory from ecology, cost-benefit analysis from economics, post-colonialism from history, and many others. We also drew insights from other pertinent interdisciplinary frameworks, such as the Social-Ecological Systems Framework by Ostrom (2007) to understand behaviours relating to common-pool natural resources.

Before the workshop, participants were asked to prepare a list of 10 key factors that they considered to shape perceptions of IAS, based on both their own work and the wider literature, and to

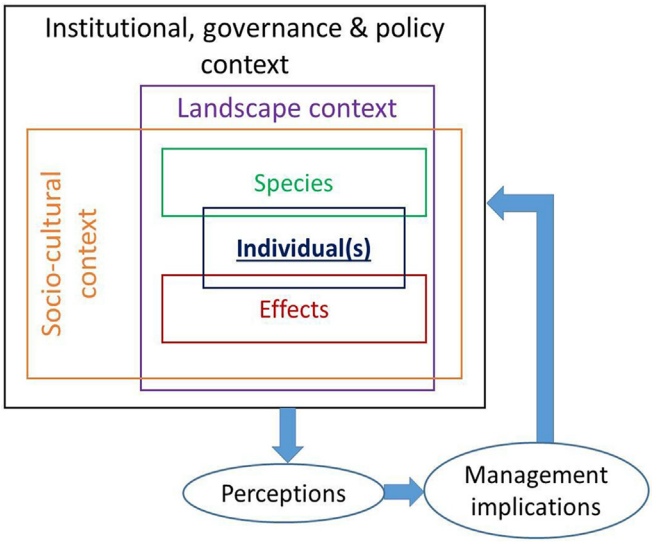

Fig. 1. A conceptual framework of the primary factors that influence peoples' perceptions of invasive alien species. Note the role of time (past, present and future) encompassing all of these factors.

provide accompanying evidence. The lists were collated into primary nodes to direct and facilitate discussion. We also considered previous efforts in the literature to synthesise information on human perceptions of IAS (for examples see McNeely, 2001; Daehler, 2008; Gobster, 2011; Kull et al., 2011; Rotherham and Lambert, 2011; Kueffer, 2013; Bennett, 2016; Kueffer and Kull, 2017). This initial exercise provided a preliminary conceptual framework which allowed us to quantify and refine key factors in the meeting. During the workshop we discussed and outlined five case studies on different invasive taxa (Boxes 1-5) to use as examples from which to draw on while discussing each factor, but also to illustrate how different factors link together and influence each other in the formation of perceptions of such taxa. The key findings from the workshop were presented to around 80 people and discussed in an open symposium at the international conference of Ecology and Management of Alien Plant Invasions (EMAPI) in Lisbon, Portugal, in October 2017, which led to further inputs and improvements in the conceptualisation of the framework.

Table 1
Underlying factors behind the primary factors outlined in Fig. 1. Note that these factors interact with each other, and are dynamic across space and time.

Primary factors in Fig. 1	Underlying factors
Individual(s)	Demographic characteristics
	Experience of species and effects
	Knowledge systems
	Sense of place
	Social relationships and group membership
	Value systems
Species	Introduction status
	Residence time
	Species traits
	Taxonomic/functional group
Effects (potential and realised)	Economic
	Ecological
	Social
Socio-cultural contexts	Land tenure system
	Management history
	Public and media discourse
	Socio-economic development
	Social institutions
	Social memory
	Social value systems
Landscape context	Availability of alternative resources (e.g., from native species)
	Ecosystem type
	Land use and cover
	Landscape beauty/scenery or attractiveness
	Management history
	Native community structure
Institutional, governance and policy context	Historical processes
	Institutional frameworks
	International agreements
	Legislation, regulation and enforcement
	Policy and governance strategy

3. The conceptual framework

Here we provide a framework of the six broad-scale factors (Fig. 1) that influence people's perceptions of IAS, which can be unpacked into more specific influencing factors (Table 1). We conceptualise human perceptions here as the result of mental processes at the individual level (one of the six sets of primary factors – in the centre), shaped by a series of other primary factors that operate at larger social and environmental scales (moving outwards from the centre) (Fig. 1).

Due to these multiple interacting factors, perceptions of IAS can be extremely complex (Woodford et al., 2016). The arrows in Fig. 1 indicate that some or all of the factors can shape perceptions, which influence people's attitudes and actions towards IAS, which in turn have implications for IAS management (Ajzen, 1985; Robinson et al., 2017). The outcomes of management interventions can then lead to changes in the contextual factors that affect perceptions, thereby leading to subsequent changes in perceptions or reinforcement of existing perceptions, producing a feedback loop which changes over time. Each of the key factors is discussed individually below, drawing on illustrative case studies and examples (Boxes 1-5). The case study boxes also illustrate how these different factors interact to shape perceptions of IAS.

We emphasise that perceptions are dynamic, mental constructs which are influenced by individuals' experiences and environments through time and space (Starfinger et al., 2003; Shackleton et al., 2007; Pagès et al., 2019; Udo et al., 2019). Although not explicitly depicted in the framework (Fig. 1), the role of temporal variability and change is stressed in the detailed descriptions of each of the factors. We further emphasise that perceptions arise and receive traction in their specific contexts and might not be transferrable to other situations (Woodford et al., 2016).

3.1. Individual(s)

Understanding of how individuals perceive their environment is primarily based on psychological approaches. When taking a psychological perspective, it is imperative to consider that while much of this research has drawn on methodological individualism, many of the underpinning mechanisms that lead to individual perceptions are better understood as shaped by socio-cultural contexts (see below; Fischer et al., 2011a). At the same time, individual experience and knowledge are also influenced by a range of other factors, as outlined below. We draw here on a number of concepts, of which some, such as beliefs, knowledge and values, can be seen to influence perceptions (as defined above) while others, such as attitudes, are synonymous with perceptions.

A key individual-level factor that shapes perceptions is individual knowledge systems. In social psychology, the term 'belief' (i.e., a mental link between an object and an attribute, Ajzen, 1988) highlights the subjective nature of knowledge. While such beliefs can be based on personal observations or experience of an IAS and its effects, they can also be informed by other forms of learning

Box 1
Case study of rainbow trout in South Africa

Rainbow trout (*Oncorhynchus mykiss*), native to the USA, has been introduced outside its native range primarily for the recreational fishing industry (Woodford et al., 2016). In South Africa and elsewhere, such as Australia, Switzerland and New Zealand, they pose a serious threat to native biodiversity and river ecosystems (Cambray, 2003). However, perceptions of this fish species differ considerably between stakeholders and are influenced by a number of different factors.

Rainbow trout were intentionally introduced to South Africa in 1876 as a sport fish, where it was perceived positively by the European settlers as there were very few alternative (native) recreational fishing species (Du Preez and Lee, 2010). Recreational anglers still view them positively. These views are partially influenced by **species** factors such as attributes of beauty, power and aggression, which are traits linked to good sports fishing. Factors related to the **effects** of rainbow trout sucth as its benefits through recreation to anglers and income for tourist industries facilitate positive perceptions for some. **Individual and socio-cultural** factors such as group membership of recreational fishing groups (e.g., Trout SA), knowledge systems and certain value systems also play a crucial role in shaping recreational anglers' perceptions. Furthermore, trout anglers in South Africa who enjoy the benefits of this fish are generally wealthy and highly educated, and so often have considerable power and influence with regards to stakeholder relations and interactions (Woodford et al., 2016). Moreover, the **landscape context** also influences recreational anglers' perceptions – rainbow trout are fished in scenic mountain streams and ponds, which links to a sense of place. Conversely, many South African scientists and conservationists generally perceive rainbow trout negatively. These negative perceptions are mainly influenced by the **effects** of this fish (such as its negative impact on native biodiversity; Cambray, 2003) combined with **individual** presovationist value systems (see Estévez et al., 2015).

These different perceptions and recently altered polices have led to conflicts around rainbow trout listing and control. The matter is complex as it was conservation **institutions** that initially had the **policy and governance** mandate to introduce these fish to improve tourism in the country. Rainbow trout were protected in South Africa by conservation legislation and actively stocked until about 1990 (Du Preez and Lee, 2010). Rainbow trout were then listed as an invasive species post 2000 on the national list of invasive alien species (RSA, 2014). These same conservation institutions initially protecting them later had the mandate to manage and control them. Anglers, however, still have a memory of previous mandates and oppose what they see as a contradictory new policy. Relating to the **socio-cultural context**, the media discourse over the conflicts of interest between anglers and conservationists has reinforced and promoted conflicts surrounding control (Woodford et al., 2016). A number of organisations, such as angling clubs and tourism boards, have also influenced anglers' perceptions, by promoting the benefits of the fish (Woodford et al., 2016).

(e.g., through educational curricula, professional contexts and the media - see below). Both qualitative and quantitative research has shown how beliefs about IAS can inform people's attitudes (i.e., evaluations; Milfont and Duckitt, 2010) towards IAS and their management. The most influential individual beliefs appear to be views on the abundance of a species, views on their effects on nature, human health and the economy (i.e., their perceived harmfulness, risks or benefits), and their perceived attractiveness. However, beliefs about the nativeness of a species do not necessarily play a strong role in informing attitudes (Fischer and van der Wal, 2007; Schüttler et al., 2011; Marshall et al., 2011; Fischer et al., 2011a; b; Van der Wal et al., 2015, but see Humair et al., 2014a). In more concrete terms, willingness to participate in IAS management has been found to be related to the costs and expected success of the management measure (Santo et al., 2015). Beliefs and attitudes will often differ between individuals as well as groups of different stakeholders (see references above; Shackleton et al., 2019b). For example, professionals in IAS management might differ from laypeople in terms of some of their beliefs (Box 1), or the strength of their beliefs, but the links between beliefs and attitudes (i.e., the way in which beliefs inform attitudes) are very similar (Fischer et al., 2014). Importantly, different experts might also diverge in their assessments and perceptions of IAS and their effects (Humair et al., 2014b; Gaertner et al., 2017). Knowledge systems related to IAS often anchor new information in existing knowledge leading to re-enforcement of certain perceptions in some cases (Selge and Fischer, 2011).

Individual value systems play a critical role in informing people's perceptions, based on attitudes and beliefs towards IAS and their management (Kendle and Rose, 2000; Fischer et al., 2011a; Verbrugge et al., 2013; Estévez et al., 2015). Psychological values are understood as situation-transcending guiding principles in people's lives (Rokeach, 1973). Values can help people to weigh different beliefs in terms of their relative importance, and a range of conservation-related values have been found to inform attitudes and perceptions towards management options (Fischer and van der Wal, 2007). Values are often conceptualised as value orientations (Manfredo et al., 2003), value types (Kellert, 1993), or visions of

Box 2
Case study of the red imported fire ants in the USA

Since its accidental introduction into the USA early in the 20th century, the red imported fire ant (*Solenopsis invicta*), native to South America, became an emblematic invasive species (Vinson, 2013). It is a notable example of how interacting factors shape human perceptions towards invasive species. The ants have ecological, social and economic **effects**. At the ecological level, examples include the decline of native insect populations (Holway et al., 2002). Socio-economic effects include crop and livestock losses, and impacts on people's health as well as damage to infrastructure (Vinson, 2013). There are also some benefits, as ants contribute to soil fertility and mineral enrichment to a small extent (Buhs, 2002). The duality of effects is dependent on the **landscape context**, changing among types of land cover and ecosystems (Hill et al., 2013); problems to human health are greater in urban areas, while negative implications for crop production are common in rural areas. Perceptions are also determined by **individuals**' value systems and knowledge, and their past experiences with the species, as illustrated in the recent floods of Hurricane Harvey (August 2017, Texas). During these floods, different public reactions emerged as fire ants formed floating rafts to survive. Whereas some people were "*fascinated by the ant colony's effectiveness in (…) floating on water, fighting other ants and building towers and underground nests*" (Tovey, 2017: The Conversation), others advised "*Don't touch the floating fire ant colonies. They will ruin your day*" (via Twitter). Among these, **public and media discourse** also took a position, for instance, announcing that "… *fire ants add new layer of horror to post-Harvey flood havoc*" (Livsey, 2017: The Guardian). These articles also show how factors in the **social-cultural contexts** such as media discourse might have an influence on how people develop their perceptions. Inevitably, these reactions relate to the **species** itself. Fire ants are insects and have some unsavoury traits (large jaws and venomous stings) and behaviours (e.g., biting and stinging when protecting nests and food resources), and have very few positive or beneficial attributes (Vinson, 2013). Therefore, unlike "cute/charismatic" animals (see grey squirrel case study; Box 4), fire ants are unlikely to attract positive perceptions based on an individual's value systems.

Fire ants are an interesting case of perceptions influenced by the intentionality of introduction and residence time. This species was accidentally transferred to the Southwestern USA, leading to different views among conservationists, scientists, and the pesticide industry. The so called "fire ant wars" during the middle of the 20th century are an example. The species was reported as a newly introduced species in the 1920s, at which time the pesticide industry showed a strong commitment to manage them and promote their products for control. The recognition of the high costs associated with the species in the 1930s has led to an eradication movement justifying the use of pesticides. These pesticides had little control efficiency but were harmful to wildlife, livestock, and humans (Buhs, 2002). Considering this management history, in the 1950s, societal institutions and organisations with different value systems arose and were against the use of pesticides and therefore had negative perceptions surrounding the control of fire ants. Some conservationists also defended ants as natural agents occupying a new niche (Hill et al., 2013), while the pesticide industry perceived ants as invasive still needing control (Buhs, 2002).

nature (Van den Born et al., 2001) related to human nature or human-landscape relationships. These can be understood as clusters of related values and normative ideals that characterise how people ought to interact with nature, and can help explain people's perceptions related to IAS (Fischer et al., 2011a; Verbrugge et al., 2013; Estévez et al., 2015) as well as conflicts over their management (Kendle and Rose, 2000; Estévez et al., 2015). Different value systems and experiences can lead to divergent perceptions – and even invasion scientists and managers show variation in their values related to IAS (Larson, 2011; Young and Larson, 2011; Gaertner et al., 2017).

Emotional factors, though more rarely investigated, play a key role in shaping perceptions. People's sense of place (shaped by physical settings/landscapes human activities and the related social and psychological processes linked to the setting (see Stedman, 2002) can be seen as an expression of emotional factors and can influence perceptions in many ways (Humair et al., 2014b). The desire to maintain a known environment can lead to negative perceptions of IAS as they might be regarded as agents of change, and thus increase support for control. However, cases of the opposite are increasingly being documented, for example, people's unwillingness to manage an invasive alien tree species on Hawaii which was seen as an element of the highly valued existing landscape (Niemiec et al., 2017); opposition to controlling introduced parakeets to which individuals develop emotional attachments (Crowley et al., 2019); conflicts around regulating rainbow trout in South Africa (Box 1) and managing grey squirrels in urban areas (Box 3). Similarly, *Eucalyptus* and *Pinus* trees in Cape Town were

Box 3
Case study of Australian acacias

Australian *Acacia* species, commonly known as wattles, have been moved around the world for over 200 years. People planted them for ornamental purposes, for profit, and for environmental management. These **species** are fast-growing, nitrogen fixing, and copious seed-producing plants; such traits makes them desirable, but also enables them to expand rapidly in many places. The resulting "acacia landscapes" exhibit a number of regional particularities in terms of social perceptions and expectations (Kull and Rangan, 2008; Kull et al., 2011; Richardson et al., 2011; Vicente et al., 2013).

At least 66 species of wattles are known to have been introduced to South Africa (Rouget et al., 2016), more than any other country. Sixteen species are currently invasive, all of which have major negative impacts in invaded ecosystems. Only one species is of major commercial importance: *Acacia mearnsii* was widely planted for its economic benefits (**effects**) for timber and tannin production leading to positive perceptions for some landowners and stakeholders in the forestry industry. Many wattles also provide important resources for local communities in grasslands where other tree species are scarce, highlighting the importance of **landscape contexts** (de Neergard et al., 2005; Shackleton et al., 2007; Ngorima and Shackleton, 2019). **Socio-cultural contexts** also mediate some negative impacts of the trees in the same area, such as issues relating to safety and security which lead to negative perceptions surrounding invasive stands, particularly for some groups of **individuals** (i.e., women who are more vulnerable to rape in dense invasive stands). Although the species are still economically important, negative impacts, such as water uptake, especially in the dry Western and Eastern Cape provinces leads to negative perceptions which relate closely to the arid **landscape context** (Fig. 1 and Table 1). Conflicts of interest regarding the management of this species delayed efforts to introduce seed-attacking insects for its biological control. Agreement was eventually reached with commercial forestry authorities and biocontrol agents have been introduced on most of the acacias. This might be promoted by the **institutional and policy context** of the country, whereby the state has a strong agenda for managing IAS which is encompassed by the Working for Water program. This program seeks to manage IAS to restore ecosystem services and provide employment to poor rural communities (van Wilgen and Wannenburgh, 2016). Decreased densities of invasive stands might lead to an overall reduction of negative **effects** and increased benefits in the future, which could lead to a change in perceptions over time, as seen with other species such as prickly pear (*Opuntia ficus-indica*, Box 5) (Beinart and Wotshela, 2003).

In Portugal, several acacias have been planted since the 19th century and many of them spread over large areas, mainly after fire events. *Acacia dealbata* and *A. longifolia* are among the most widespread, with significant negative ecological **effects**, namely reducing native plant communities, changing nutrient cycling and altering the landscape (Marchante et al., 2008, 2015; Lorenzo et al., 2010; López-Núñez et al., 2017). Since 1999 eight species have been categorised as invasive by Portuguese legislation (Ministério do Ambiente, 1999) resulting in restrictions on planting and selling these species, which is an **institutional and policy context** that may influence perceptions. Although many people nowadays are aware that they are invasive, and many projects aim to control them in conservation and production areas (perception resulting from economic **effects**), some people see them as a benefit, using some species for firewood or organizing photographic safaris while they are blooming (**species factor**). Back in the 1980s there was even a "Festa da Mimosa" (Mimosa festival) in the north of the country celebrating *A. dealbata* which links closely to **individual** and **socio-cultural** value systems (Fernandes, 2012).

In Madagascar, wattles have long been promoted (since the 1900) for their use in re-greening landscapes perceived to be degraded and barren (discourse: **socio-cultural factors**), their economic returns through use as wood fuel, tanbark, or timber products (**economic effects**), and their perceived environmental contributions in terms of reducing soil erosion (**ecological effects**). The main introductions have been *A. dealbata* and to a lesser extent *A. mearnsii* in the highlands and *A. mangium* in the eastern and northern lowlands. While acacias clearly demonstrate behaviour that ecologists would classify as invasive (rapid expansion, achieving dominance over previous vegetation: **ecological effects**) in the highlands, most rural villagers and government foresters perceive this as positive, due to the aforementioned factors (Kull et al., 2007). In contrast, lowland farmers currently perceive *A. mangium* as problematic, as they are not (yet) benefitting from its utility and because it shades out clove trees and makes the soil 'hard' or sterile (**effects**), in contrast with a highly-appreciated *Grevillea banksii* invasion (Kull et al., 2019).

In Vietnam, approximately 1.1 million hectares of tropical Australian acacias (especially a hybrid of *A. auriculiformis* and *A. mangium*) have been planted since the 1990s. This 'regime shift' in the land system (Kull et al., 2017) was facilitated by several factors, including land tenure reforms, concern over deforestation, and a hungry export-oriented wood processing industry (de

Jong et al., 2006; Meyfroidt and Lambin, 2008; McElwee, 2009; Thulstrup et al., 2013; Nambiar et al., 2015). These acacias, and their rapid expansion, are perceived quite positively by many actors, for different reasons. For one, they are the most visible manifestation of government land allocation programs (**policy and governance**) which allow households and communities to gain title to land from which they were previously excluded. As such the acacias have value beyond their profitability. Indeed, economic returns have a preponderant economic "**effect**" on perceptions, as many industries, rural entrepreneurs, and poorer villagers alike are dependent on the acacia economy. At least half of the plantations are owned by households in areas of a few hectares; Vietnam has more than 3000 wood processing companies and exports globally as a top producer of wood furniture and hardwood chips for the pulp industry (Phuc and Canby, 2011). Outside scientists have attempted to raise the alarm about acacia invasiveness (Richardson et al., 2015), yet several factors mitigate against such perceptions. One is **species** factors, as the widespread acacia hybrid used in cultivation is not perceived to produce vigorous seeds, and few (if any) problematic invasions have been documented. Another is the **landscape context**, where any potential acacia spread is mitigated by the density of the population and the intensity of its rural land use, meaning there are few 'invasible' tracts. A final one is the **socio-cultural context**, whereby challenges to the dominant framings of the positive contributions of acacia plantations (in land allocation, in economic returns, in re-greening barren lands) simply have little room.

thought by many residents to give the area a sense of place, which resulted in conflicts over their proposed removal (Gaertner et al., 2016) and in Switzerland some invasive species were even perceived by many to be native (Lindemann-Matthies, 2016). Indeed, the desire for a sense of place has in some cases led to the active introduction of some IAS. In the past, colonial settlers translocated plant and animal species from their countries of origin precisely to re-create familiar biota and landscapes in their new environment (Mack, 2001; Borowy, 2011).

Considering social interactions and affiliations to social groups can help to understand the context in which individuals' knowledge and value systems develop (Norgaard, 2007; Niemiec et al., 2017). Often, demographic characteristics (e.g., age, education, ethnicity, gender, income, occupation; or urban/rural residence) are essentially used as proxies that are easy to assess (Bremner and Park, 2007). However, these only gain meaning if we interpret them as socio-cultural factors that relate to socially-shared experiences. This line of research has also compared the views of different stakeholder groups (García-Llorente et al., 2008; Touza et al., 2014; Shackleton et al., 2015), groups of experts (Bardsley and Edwards-Jones, 2007; Humair et al., 2014b), experts and laypeople (Selge et al., 2011; Fischer et al., 2014; Van der Wal et al., 2015), affected communities and external experts (Estévez et al., 2015) and found links, such as between value orientations (see above) and level of education (Fischer et al., 2011a; Shackleton and Shackleton, 2016). It is worth noting that all of these factors are dynamic and change through learning processes, such as hands-on experience in IAS management or through engagements between stakeholders (Novoa et al., 2016, Pagès et al., 2019).

3.2. Species

As perceptions are mental constructions of an object, they are influenced by the attributes of that object (IAS in this instance), such as the species' traits and their taxonomic and functional characteristics (Table 1). The perception of IAS with specific traits or within a particular taxonomic group needs to be considered in a wider context of visions of nature, i.e., the meanings people attribute to nature or a species based on their experience, beliefs and knowledge of it (Verbrugge et al., 2013).

Some invasive animals, such as rats (*Rattus* spp.) with naked tails, cane toads (*Rhinella marina*) that exude slime, or fire ants that bite and sting (see Box 2), provoke fear or disgust, so they are often perceived in a negative light as undesirable or ugly (Veitch and Clout, 2001; McNeely, 2001; Batt, 2009; Shine and Doody, 2011; Ormandy and Schuppli, 2014; Kueffer and Kull, 2017). By contrast, people often have positive perceptions surrounding animals that have neotenic features (big eyes and large heads); that are colourful, quirky, small and fluffy; or that are large and majestic, which leads people to view them as "cute or charismatic" (Sharp et al., 2011; Estévez et al., 2015). Examples of animals that are perceived more positively by many groups include the colourful and "friendly" mallard duck (*Anas platyrhynchos*) and the big-horned Himalayan tahr (*Hemitragus jemlahicus*) in Cape Town (South Africa), the large eyed and quirky common coqui frog (*Eleutherodactylus coqui*) in Hawaii, large charismatic feral horses (*Equus caballus*) in Australia, and the small and fluffy North American grey squirrel (*Sciurus carolinensis*) in Europe (see Box 4) (Bertolino and Genovesi, 2003; Serpell, 2004; McNeely, 2005; Nimmo et al., 2007; Kraus, 2008; Gaertner et al., 2016; Novoa et al., 2017). Moreover, human perceptions of large mammals are often more positive than those of some rodents or non-mammal taxa, such as reptiles or insects (Fitzgerald et al., 2007). Sentience of the species also plays a crucial role with regards to how people view IAS management, especially relating to control methods, whereby, people are more likely to oppose the lethal control of mammals and birds than insects or plants, which often links to perceptions and values associated with animal rights and welfare (Warburton and Norton, 2009; Olszańska et al., 2016; Villatoro et al., 2019). Similarly, people often have negative perceptions of thorny plant invaders such as the common gorse (*Ulex europaeus*) in New Zealand and Reunion (Veitch and Clout, 2001; Udo et al. 2019), but feel positive about invasive plants with colourful flowers, such as the jacaranda tree (*Jacaranda mimosifolia*) in South Africa (Dickie et al., 2014). In some contexts, a forest of invasive trees may be perceived as a healthy ecosystem, while an area invaded by trees in a treeless biome might be perceived as a degraded area (Richardson et al., 2014).

Species with traits that are useful for people, such as Australian acacias that produce wood and tannins (Box 3) or prickly pears that bear edible fruit and provide fodder (*Opuntia ficus-indica*) (Box 5) link to positive or mixed positive and negative perceptions for many stakeholders due to their beneficial economic and livelihood effects (Shackleton et al., 2007; Zengeya et al., 2017; Shackleton et al., 2019a).

The introduction history of a species is also important. Residence time influences perceptions of a species in different ways. IAS whose resident times are longer are more readily perceived as native (Garcia-Llorente et al., 2008; Humair et al., 2014a; Kull et al., 2014; Shackleton et al., 2007), as they may have become incorporated into social memory. Conversely, an IAS can increase in abundance over time and have more substantial effects on people

Box 4
Case study of grey squirrels

The Eastern grey squirrel (*Sciurus carolinensis*), native to eastern North America, has been introduced repeatedly to several European countries, notably Ireland, Great Britain and Italy (Bertolino, 2009). It has also been introduced to Australia (where it was extirpated by 1973), South Africa, and to many islands (e.g. Azores, Hawaii, and Madeira Island) (Long, 2003). It was brought in primarily as an 'ornamental' addition to parks and gardens, and has since then become naturalised and invasive in many parts of its introduced range. Grey squirrels remain popular visitors to urban and suburban gardens and park **landscapes** (Bonnington et al., 2014); indeed, in some areas they are one of few urban mammals people might encounter. There are therefore both potential and realised social conflicts surrounding management or eradication initiatives (which normally involve extensive lethal control - a form of management which leads to negative perceptions of control and support for IAS based on many **individual** value systems).

Perceptions of squirrels are often influenced by **species** factors such as its appearance and 'charisma' (see Lorimer, 2006). Many people find the large eyes and bushy tails of squirrels appealing; however, others dislike their more typically rodent-like characteristics (e.g., pointed nose, large incisors). Factors related to the negative **effects** of the species such as the displacement of the native red squirrel (*Sciurus vulgaris*) in the UK and Italy (Bertolino et al., 2013), damage to forestry and amenity trees by bark stripping (Nichols et al., 2016), and nuisance behaviours in houses and gardens may also drive negative perceptions of this species in some areas.

Individual factors such as people's experience of the species and its effects will further influence how squirrels are perceived. For example, some may have positive experiences such as watching squirrel acrobatics and feeding them, linking to human values such as aesthetic and humanistic appeal (Estévez et al., 2015), while others may experience aggressive behaviour or witness disturbance in their gardens. Many people perceive squirrels as sentient individuals with intrinsic value, irrespective of their origin or effects (Perry and Perry, 2008), and argue that they therefore have the right to live and/or not be caused to suffer (i.e., animal welfare concerns). For example, in Italy, an animal rights group challenged the legality of an eradication attemp (Bertolino and Genovesi, 2003) based on moralistic or ethical concerns and values.

The **landscape context** also affects people's perceptions. Squirrels are often encountered in urban parks, due to the presence of large trees suitable for nesting and feeding and the absence of competition and predation pressure (Bertolino, 2016); thus, they are more likely to be seen and become familiar components of people's experiences. They also offer some degree of biodiversity value as wildlife in landscapes which may otherwise contain very few wild animals.

Sometimes **policy and governance** may have little effect on influencing perceptions of squirrels. For example, in South Africa, grey squirrels are nationally listed as an invasive species, however, it has been suggested that their aesthetic benefits, and low public support for control, offset their (currently minor) negative biodiversity impacts (Gaertner et al., 2016). Consequently, despite legislation requiring the control of this species in some provinces, tolerating them may be the most appropriate management alternative in other parts (Gaertner et al., 2017) – but that differs from Italy (mentioned above). However, the broader **socio-cultural context** is important. For example, public discourses may affect perceptions; in Italy, media stories surrounding grey squirrels expansion included military metaphors describing them as "invaders" (*Country Life* 11 February 1993), and attempted to associate them with 'vermin' by describing them as "tree rats" (see Jerolmack, 2008). In the UK, grey squirrels are more likely to be perceived negatively by supporters of native red squirrels (*S. vulgaris*), which have longstanding cultural significance as well as aesthetic appeal (Lurz, 2014). This effect is particularly apparent in areas where remaining red squirrel 'strongholds' are threatened by expanding invasive grey squirrel populations (Dunn and Marzano, 2015).

and the environment, which can lead to a shift from them being perceived as beneficial or non-threatening towards more negative perceptions, as was the case of prickly pears (Box 5). Perceptions may also differ spatially in relation to an invasion gradient, as in the case of Siam weed (*Chromolaena odorata*) in Tanzania, where perceptions of the plant were different at the invasion front (sparse invasions) compared to where the species was well established (core areas) (Shackleton et al., 2017). In the core areas, this species

Box 5
Case study of prickly pears

The case of prickly pears (*Opuntia ficus-indica*) provides stories of how perceptions have changed with time based on the interactions of a number of the factors mentioned in Fig. 1 and Table 1. In South Africa, this plant was initially promoted by governmental **institutions** through **policies** to increase the productivity of the country's arid lands. Introductions prompted by the government were welcomed by farmers as the **species** provided valuable **effects** such as fodder and food source which could increase profits and so was viewed in a positive light - particularly in arid **landscape** areas with low productivity (van Sittert, 2002).

With time, however, prickly pear became extremely invasive, leading to wide-scale spread. At the height of invasion, it covered around one million hectares of South Africa, leading to negative **effects** on livestock production and mobility of people, and altered landscape aesthetics therefore having negative implications for human well-being. This led to a switch towards a negative view of the plant, which was also likely fuelled by media discourse and the government declaring the **policy** of a state of emergency due to the negative effects of this invasion. This led to the development of an effective biological control programme (Zimmermann and Moran, 1991; Beinart and Wotshela, 2003). A cochineal (*Dactylopius opuntiae*) and moth (*Cactoblastis cactorum*) were released and within a few decades, cover was reduced to less than 100 000 ha. This led to substantial impact reduction and a larger supply of benefits from the plant but also from other services in the landscape, and change towards more positive perceptions for the species again (Zimmermann and Moran, 1991; Shackleton et al., 2011). Some **individuals** and communities even mentioned that they would not mind if densities increased slightly due to the benefits it provides, subsequent adoption of the species into local **socio-cultural** practices (Shackleton et al., 2007; Beinart and Wotshela, 2003). Similar experiences with prickly pear can be seen in Australia, although the return of perceived benefits post control is less likely as there are fewer poor communities in Australia relying on the fruit for their livelihoods.

In contrast, in southern Madagascar the biological control of *Opuntia monocantha* in the 1920s and more recent management efforts on other *Opuntia* taxa have had controversial effects on local communities, who had adapted their livelihoods and **socio-cultural** practices around the use of the cactus and never had the same negative perception of the species as seen in South Africa (Binggeli, 2003; Kaufmann, 2008; Middleton, 2012). In this case, having a baseline assessment of local perceptions would have been crucial to highlight that no management was actually needed, and would have prevented negative impacts as a result of control on many local communities in Madagascar. It also suggests that different contexts play a crucial role in determining people's perceptions and they differ considerably in different settings. It therefore reinforces the role of understanding people's perceptions thoroughly before policy development and management implementation.

was seen as more problematic, leading to more pronounced negative perceptions and more support for control.

3.3. Effects

Effects can be understood as changes to social-ecological systems, or parts thereof, as a result of IAS (Simberloff et al., 2013; Vaz et al., 2017a). The direction of effects can be either positive or negative (Jeschke et al., 2014), and can be valued in relation to economic, ecological and social implications, depending on different human judgements and values (Liu et al., 2011; Jeschke et al., 2014; Vaz et al., 2017a; Shackleton and Shackleton, 2017) (Table 1). The effects and corresponding perceptions of IAS can also differ among stakeholder groups, which can result in conflicts of interest. For instance, the effects of introduced *Prosopis* trees on the landscape, rural economy, society, and livelihoods of local communities from India, South Africa or Malawi are perceived as having both benefits (charcoal, fodder and fuelwood provision) and costs (impact on water supply and human and livestock health) (Shackleton et al., 2014), which is similar to Australian acacias (Kull et al., 2011) (Box 3). In such cases, perceptions often vary substantially between different groups of stakeholders based on differing degrees of benefits and costs for livelihood practices (Shackleton et al., 2015); in the same community, fuelwood sellers would value and perceive Australian acacias or *Prosopis* as more positive as they are gaining a key resource, compared with agricultural farmers who will bear additional costs for clearing fields (cf. Robbins, 2001; Shackleton et al., 2015).

Similarly, species might not have economic costs but have positive effects through providing cultural services (Eviner et al., 2012; Dickie et al., 2014; Estévez et al., 2015; Vaz et al., 2017a, 2018). These cultural services link to intrinsic, aesthetic and recreational benefits provided by IAS (e.g., rainbow trout and grey squirrels (see Boxes 1 and 4), as well as numerous plant species like

jacarandas (Dickie et al., 2014). Some species have no or very few benefits, and substantial negative effects on biodiversity, ecosystems and human well-being, such as fire ants (Box 2) or the invasive, herbaceous plant, famine weed (*Parthenium hysterophorus*) (Kaur et al., 2014). Consequently, perceptions of these species will generally be negative.

IAS effects are not uniformly perceived in space and time, i.e., their perception depends on the magnitude and rate of the invasion process (Shackleton et al., 2007; see Boxes 3 and 5). Dehnen-Schmutz et al. (2007) note that ornamental IAS can be seen as having aesthetic benefits when confined to private gardens, but shifts in perceptions may occur when they become widespread in the wild, leading to economic and environmental costs. This has been documented in Britain both for Japanese knotweed (*Reynoutria japonica*), the common rhododendron (*Rhododendron ponticum*) and the ruddy duck (*Oxyura jamaicensis*) (Bailey and Conolly, 2000; Milton, 2001; Dehnen-Schmutz and Williamson, 2006). In anthropology, this phenomenon has been described as 'boundary maintenance', i.e., (groups of) people might see a species in a certain place (where the species is seen to 'belong') as positive, whereas the same species is seen 'out of place' when it moves beyond the allotted space. Boundaries are, in this sense, not only spatial (i.e., between different countries, or between parks and natural spaces) and temporal (i.e., the rate at which the species move between boundaries determines whether their effects are perceived as novel or part of the system; see also section 3.2 - Species) but also conceptual, for example, where hybridisation with the ruddy duck threatens to effectively cause the extinction of the native white-headed duck in Spain (Milton, 2001).

3.4. Socio-cultural context

By 'socio-cultural' context, we refer to factors that shape perceptions through the ways in which people interact with each other in the social realms of rules, traditions, practices and ideas (Norgaard, 2007; Kull et al., 2011). Some of these factors (Table 1) are 'structural', or longer lasting and pervasive, while others might be seen as more dynamic or 'fluid'. Many of the 'individual-level' factors described above, including perceptions of IAS effects, are likely best understood in their socio-cultural contexts, as they are shaped and developed not in a vacuum but in interaction with others, either directly through conversations and shared practices, or indirectly, e.g., through the media and educational curricula.

Structural factors include social institutions and rules, such as land tenure systems. Reactions to IAS may differ depending on whether it is "on my land", "on their land", "on government land", or "on conservation land", depending on rules, traditions and covenants shaping land access and use (Box 1). For example, in some regions such as South Africa, state agencies have struggled with inspiring and enforcing IAS management actions on private land as IAS are viewed as a state issue (Urgenson et al., 2013). In other areas, such as the UK, government agencies have recently been granted powers of access to private land for the purposes of IAS control (Infrastructure Act, 2014), which could either increase negative perceptions of IAS or negative perceptions of managing authorities – potentially leading to resistance to management (Crowley et al., 2017b). Mackenzie and Larson (2010), demonstrate in a Canadian context a loss of trust in government authorities after an unsuccessful 'rapid-response' program that sought to control the emerald ash borer.

The level of socio-economic development is another structural factor. People of all income classes, in wealthy or impoverished regions, may be concerned with IAS, but the kind of issues and management challenges raised, and consequently perceptions, tend to differ, for instance between subsistence farmers in poor regions and gardeners in wealthy suburbs (Nuñez and Pauchard, 2010; Kull et al., 2011; Shackleton et al., 2015). Social structures, whether class, race, gender, or ethnicity, not only shape how invasive species affect people, but they are also identities which people may mobilise in campaigns for or against particular species. For instance, in northern California, Native American identity and gender formed the basis of social mobilization against herbicide use to manage an invasion of spotted knapweed (Norgaard, 2007).

Broader social value systems and social institutions are a third example of a structural factor that can influence perceptions. Individual value systems (see above) are shaped by, and inform, broader societal ideologies; these may be broad cultural or religious norms and values, or specific ethical value systems adhered to by special interest groups such as biodiversity conservation or animal rights advocates (Minteer, 2013). In New Zealand, some Maori groups perceive *kaitiakitanga* (guardianship responsibilities) towards invasive kiore (*Rattus exulans*) (Kapa, 2003), and in Australia, aboriginal perceptions of introduced species may diverge from the ('Western' scientific) narratives of invasion and control (Trigger, 2008). Similarly, values communicated by media narratives and heightened exposure of some IAS might also affect perceptions (Touza et al., 2014, and Box 2).

Social memories, both of IAS and previous attempts to manage them, are a more fluid socio-cultural factor. Over time, people may positively associate IAS with particular locales, and some can even become integrated into conceptualisations of community and socio-cultural identity as seen with trout fisherman (Box 1), adoption and use of Australian acacias and prickly pears in some communities (Boxes 3 and 5), and in many other cases (Mackenzie and Larson, 2010; Crowley et al., 2019). Alternatively, they might negatively associate the arrival of an IAS with its effects, such as the loss of valued species and landscapes (Lurz, 2014; Vaz et al., 2017a), as in the case of red and grey squirrels (Box 4). Historical disputes and costly management failures can affect how people weigh up the relative risks and benefits of a species' presence against those of its control (Crowley et al., 2017a). Middleton (2012) documents how, in Madagascar, stories told by different stakeholders about the control of the *Opuntia* cactus through the release of biological control insects in the 1920s (which was subject to strident debate and contributed to a major famine) became "a powerful rhetorical tool in the context of a present-day controversy over another prickly pear. Experience of biological invasions in the present has been reshaping historical memory, while reinterpreted narrative of past biological control is informing current debates" (Middleton, 2012; see Box 5).

These diverse factors are often tied together in 'frames' or 'discourses' that shape perceptions by constraining the ways in which a phenomenon is understood, and the types of solutions that can be proposed (Landström, 2005; Larson, 2010; Javelle et al., 2010; Prévot-Julliard et al., 2011; Head and Atchison, 2015; Kull and Rangan, 2015; Head, 2017). An illustrative example from the case of Australian acacias (Box 3) is the influence of 'environmental imaginaries' on perceptions and different social-ecological contexts in different countries (Kull and Rangan, 2008; Kull et al., 2011; Ngorima and Shackleton, 2019). Social relationships between actors involved in IAS management can strongly shape IAS perceptions, and these relationships can change through participatory processes or when conflicts emerge (Humair et al., 2014c; Shine and Doody, 2011).

3.5. Landscape context

Many different definitions for landscape exist, but structural or ecological landscapes consist of areas of land containing different mosaics of patches, elements or ecosystems that often repeat

themselves leading to some form of heterogeneity (Forman and Godron, 1986; Turner et al., 2001). Within the landscape context, land use and cover and ecosystem type are the key likely factors facilitating perceptions of IAS, with other factors such as history of landscape management, landscape attractiveness and availability of alternative natural resources also contributing to how people perceive IAS (Table 1). The landscape context is intimately related to people's cognition as landscapes are viewed through human eyes and recalled by individuals (shaped by human-nature interactions) (Meinig, 1979; Nassauer, 1995).

Perceptions of IAS in highly transformed ("unnatural") urban landscapes may differ considerably from more rural farmlands or conservation areas where they are perceived as more problematic (Shackleton et al., 2015; Salomon Cavin and Kull, 2017; Boxes 1 and 4). This change in perception along an urban-rural gradient is linked to the level of exposure and effects (impacts) of IAS in certain landscapes, the level of modification influencing what is perceived as natural or not, and general landscape aesthetics (Table 1). Land use also influences perceptions of different stakeholder groups. For example, a fishing tourism agency operating on private land is more likely to have positive perceptions of rainbow trout (Box 1) than the managers of a protected area nearby; these perceptions are therefore linked to the primary land use and associated mandates and goals for the landscape. Similarly, invasive tree taxa such as Australian acacias (Box 3) will be perceived very differently in different landscape contexts based on land use and ecosystem type (Kull et al., 2011; Kull et al., 2019; Shackleton et al., 2019a). For example, acacia trees in treeless grasslands may provide a novel resource (wood) and may be perceived in a positive light (Ngorima and Shackleton, 2019) as opposed to landscapes where other trees are available. Alternatively, for non-resource users the introduction of trees into treeless landscapes might represent negative perceptions relating to a sense of place. Some species such as fire ants (see Box 2), may be perceived negatively in all landscapes as they provide little to no benefits to people and have high costs. Similarly, management practices in the landscape (Table 1) such as the introduction of biological control agents and the subsequent reduction of IAS densities across large areas might change people's perception of these species from negative to positive over time, such as in the case of prickly pears (Box 5), making it important to understand broader historical landscape contexts and management implications (Beinart and Wotshela, 2003; Bennett and van Sittert, 2019; Udo et al., 2019).

3.6. Institutional, governance and policy context

Policy and governance contexts influence people's perceptions of IAS through the capacity of institutions and policies to shape individual values, influence social relationships, and motivate or constrain attitudes and behaviours towards IAS from international to local levels. They represent more formalised and larger scale structural socio-cultural factors. These broader institutional and policy contexts are often the overarching factors influencing other factors listed in Fig. 1 and Table 1, they are often driven by historical processes, and they have long term implications.

Historically, the earliest and most sustained policy and governance efforts to regulate IAS have happened at state or national level and initially focused on protecting agriculture (Stoett, 2010; Kull and Rangan, 2015; Hoffmann and Broadhurst, 2016). This emphasis on national boundaries and differences between countries has reinforced ideas of nationalism, which in many instances influences how people perceive invasive species (Head and Muir, 2004; Kueffer and Kull, 2017). Early legislation (early to mid-1900s) required individuals to manage species, but over time government institutions and expert-led management efforts became more important to avoid free-riding, and large landscape scale invasions required research and technical aid beyond the capacity of the individual, possibly influencing changes in perceptions of responsibility for control (Urgenson et al., 2013; Lubell et al., 2017). The recent push towards integrative governance has sometimes led to collective action strategies to organise diverse stakeholders to achieve management goals which can change perceptions of different groups of stakeholders through institutional interactions (Bryce et al., 2011; Novoa et al., 2016; Pagès et al., 2008; Shackleton et al., 2019b).

More recently, there also has been an expansion in policy that traditionally focused on the agricultural sector, to include wider conceptions of biodiversity (protected areas), ecosystem services, and human well-being and livelihoods (Foxcroft et al., 2017; Vaz et al., 2017a). This also links to the socio-cultural shift relating to the rise of international environmentalism and growing celebrations of indigenous biodiversity and identity, and the promotion of nature-based tourism (Kueffer, 2013; Bennett, 2014, 2016, 2017). IAS with use value, such as Australian acacias, or prickly pears (Boxes 3 and 5) or sport fish such as rainbow trout (Box 1), were rarely perceived as problematic invaders by any stakeholders prior to the growth in popular appreciation of indigenous species and ecosystems (Bennett, 2014; Bennett and van Sittert, 2019). Many expert-led interventions and policies have been criticised for disregarding indigenous viewpoints and institutions, and for downplaying local uses of invasive species (Bach et al., 2019; Kull et al., 2019). This has led to conflicts over policy and legislation in the case of trout and other species (see Box 1) (see Gaertner et al., 2016) and negative impacts as a result of management for local livelihoods, as seen with prickly pear in Madagascar (see Box 5).

Globalisation has led to increasingly high levels of species introductions (Seebens et al., 2017), and a growing number of international organisations are now involved in IAS management. This has led to a number of international agreements and policies to try and curb invasions (Brunel et al., 2013). Some of these include the United Nations Convention on Biological Diversity (CBD), the International Plant Protection Convention (IPPC) of the FAO and the World Trade Organization Agreement on the Application of Sanitary and Phytosanitary Measures (The SPS Agreement), all of which aim to influence national and local institutions and governance.

Around the world, national governance contexts vary widely despite many countries having similar histories of globalisation. For example, imperial administrations and aid agencies and organisations (e.g., British, French, US: UNEDP, FAO) promoted the introduction of many IAS for plantations and agroforestry outside of Europe (Bennett, 2015). However, in Australia and South Africa, policy directed at managing invasive *Prosopis* focuses on reducing impacts using manual and biological control, whereas in Kenya, national policy focuses on promoting utilisation of the tree which might influence different local perception of the species in the different countries (Shackleton et al., 2014). In India, legislation and policies to protect indigenous vegetation has led coffee farmers to prefer IAS over native species because IAS are not protected by law and thus can be cut for timber production, leading to positive perceptions of these species (Nesper et al., 2017). In South Africa and New Zealand, the constitution allows central government organisations to actively manage land throughout the whole country thus pushing a particular agenda and influencing perceptions more strongly in a certain way (van Wilgen et al., 2012). In other contexts, management is more de-centralised, as in Switzerland (Fall, 2013), possibly leading to more diluted views of IAS. In a number of areas, governance surrounding IAS is simply absent (e.g., many Latin American countries) likely leading to different perceptions in different regions (Speziale et al., 2012). Australia and New Zealand promote strict biosecurity policies, whereas other regions lack

policies for enforcement or capacity for biosecurity practices (Bacon et al., 2012; Early et al., 2016), which we suspect may influence the awareness and perceptions of broader publics in these different regions. Increasingly, focusing on policy and managing introduction pathways instead of individual species policy frameworks has had important consequences for how people think about and perceive invasion issues (Kueffer and Hirsch Hadorn, 2008; Andreu et al., 2009; Hulme et al., 2017).

Over time and through historical processes, government policies and legislation related to particular IAS can shift substantially from promotion to control and in some cases acceptance and vice versa, for instance in the case of *Tamarix* in the USA (Stromberg et al., 2009), black cherry (*Prunus serotina*) in Europe (Starfinger et al., 2003), cinnamon (*Cinnamomum verum*) in the Seychelles (Kueffer et al., 2013), gorse (*Ulex europaeus*) in La Réunion (Udo et al., 2019), trout in South Africa (Box 1) and prickly pear in many regions (Box 5). We suspect that time lags between policy processes and expert or stakeholder deliberations can likely lead to policies that differ considerably from perceptions in science or society.

4. Discussion and recommendations

4.1. Factors shaping people's perceptions

Perceptions of IAS can be highly context specific, and vary substantially between different individuals, groups and areas (e.g., countries and landscapes) and over time (Shackleton et al., 2007; Gobster, 2011; Kull et al., 2011; Shackleton et al., 2019a; Udo et al., 2019). This is similar to perceptions of other contentious environmental issues such as the use of Genetically Modified Organisms (GMOs) (Nelson, 2001; Frewer et al., 2004; Doh and Guay, 2006). However, there are recurrent processes and patterns in situations that can be identified. The conceptual framework presented in this paper has arisen from an attempt to organise these patterns, drawing on the literature on perceptions of IAS in a wide range of disciplines. The inclusive and interdisciplinary nature of this framework means that we had to accept some vagueness of definitions – e.g., we used the term 'perceptions' as an umbrella concept that subsumed more narrowly defined constructs such as 'attitudes' but at the same time can also be seen to be shaped by these narrower constructs – and overlap between factors. For example, depending on disciplinary perspective, value systems can be simultaneously seen as individual-level, socio-cultural or governance-related factors. Beliefs about plant or animal species (as described in the section on individual-level factors) are inherently – but not rigidly – connected to biological features and effects. Changes in perceptions over time and space might be best understood as changes in individual-level, socio-cultural or governance factors, or as changes in landscape context, and these changes can drive or be driven by management interventions. The different components of our framework are thus both conceptually and empirically closely linked with each other.

4.2. The importance of understanding perceptions for management

Much previous research about perceptions in invasion science, especially that of academics with a training in natural science, has often (implicitly) tended to ask 'Why are some people's perceptions different from ours (researchers) and what can we do to get such people to perceive the problem in the same way we do?' However, with the use of this framework, we highlight that in many instances understanding different perceptions should be at the centre of research and management, and not as an end-of-study add-on to incorporate stakeholders into an IAS agenda. This is crucial, not least because many cases of conflict over and opposition to management actions have arisen from a clash in perceptions between different stakeholder groups (Bach et al., 2019; Milton, 2001; Gaertner et al., 2016; Crowley et al., 2019; Shackleton et al., 2019b). Having a broad scale framework can aid researchers in better understanding perceptions and may guide managers and policy makers in the planning and implementation of management.

Understanding perceptions will highlight where there might be potential conflicts surrounding the management of particular IAS, especially those with both positive and negative attributes and effects (Boxes 1, 3, 4, 5). Furthermore, conflicts can arise over control techniques (particularly in relation to animal welfare) and having knowledge about local perceptions can also help to mitigate these (Olszańska et al., 2016; Crowley et al., 2019; Villatoro et al., 2019). Having this information can enable the development of programs to engage and inform stakeholders (Novoa et al., 2018; Shackleton et al., 2019b). This can be used to try to bring opposing groups towards cooperation and even consensus, as seen with cactus species in South Africa (Novoa et al., 2016). It can also allow for the development of management practices that are acceptable for all stakeholders.

Similarly, understanding perceptions can help to prioritise the management of IAS to ensure greater societal benefit. For example, case studies in Nepal show that the impacts and perceptions of a number of IAS in the same locality differ, that some have much greater adverse effects, and that management should therefore be focused on them (Rai et al., 2012; Shrestha et al., 2019). This is similar to Gaertner et al. (2016) who assessed perceived benefits and costs of different IAS in an urban setting to assign them different management priorities and approaches. Furthermore, understanding perceptions of a single IAS amongst different stakeholders and landscapes can help prioritise funding to areas where negative perceptions (often linked to greater impacts) are highest and to protect stakeholders who are most vulnerable (Shackleton et al., 2015). Lastly, in some cases, understanding perceptions, especially if they are predominantly positive, can help target acceptable species management approaches or avoid control all together (Clavero, 2014). This prior knowledge would have been useful to avoid the negative consequences of biological control for *Opuntia* spp. on local livelihoods in Madagascar, where control went ahead as initial perceptions were not assessed (Binggeli, 2003; Kaufmann, 2008; Middleton, 2012) (Box 5).

Understanding perceptions can also encourage research and guide management of IAS. For example, in a number of countries, options for managing invasive *Prosopis* have been limited as past literature and many political stances viewed the tree as having primarily beneficial effects and assumed people perceived the tree in a positive light. However, more recent research in different countries has shown that many people actually perceive this invasive tree a serious threat and would support management to reduce its negative effects (Mwangi and Swallow, 2008; Mosweu et al., 2013; Shackleton et al., 2015; Duenn et al., 2017). For example, in South Africa this new evidence of negative impacts and perceptions justifies doing research into the release of more effective biological control agents which were previously limited (Shackleton et al., 2015).

Knowledge of perceptions can also help with good practice in IAS management (Estévez et al., 2015). This includes engaging and involving stakeholders in decision making and management processes (Shackleton et al., 2019b), leading to improved transparency and a genuine acknowledgment of different actors' views and concerns. This can also help to build collaboration and trust between different actors, which fosters longevity and effectiveness of control actions (Halford et al., 2014; Novoa et al., 2016). More participatory approaches can also help to address the negative implications of a knowledge "deficit model" whereby scientists and

managers often see other stakeholders as a homogenous group of people who have to be educated (Fischer et al., 2014; Moon et al., 2015).

Furthermore, having a better understanding of stakeholders' knowledge, perceptions and practices can help in predicting future introductions and spread of IAS and thereby catalyse policy and management strategies to counteract this (Cole et al., 2016; Cole et al., 2019). For example, recreational boaters in the USA act as vectors of spread of IAS in freshwater systems through the transport of boats to and from different waterbodies. Therefore, government institutions implemented a large-scale awareness and education program to help to change boaters' perceptions on the risk of IAS, and improve the implantation of preventive measures to reduce future introductions. However, recent studies show that this helped to change perceptions and practices for some boaters, while many just did not care, or even knowingly introduced IAS (Cole et al., 2016; Cole et al., 2019). Cole et al. (2016) conclude that although such awareness campaigns have been somewhat successful in changing perceptions and practices, this strategy alone may not be sufficient to prevent future introductions and therefore other and complementary policy and management options and approaches have to be considered to improve effectiveness in the future.

4.3. Past advances and future needs

Acknowledgment of the importance of research that aims to understand human perceptions in invasion biology and conservation has grown steadily in recent years (García-Llorente et al., 2008; Kull et al., 2011; Kueffer, 2013; Estévez et al., 2015). This has led to great advances in understanding in some areas, especially through the adoption of approaches from different disciplines (Estévez et al., 2015). For example, there is a good understanding and a large research base from the ecological domain on species traits and correlated effects, which can link closely to how people perceive IAS (Zengeya et al., 2017). Further, understanding of the social-ecological effects of IAS has grown steadily, especially with the rise of ecosystem services literature, and we are starting to gain understanding as to how this might influence people's perceptions (Vaz et al., 2017a, 2018; Ngorima and Shackleton, 2019; Potgieter et al., 2019). Understanding of individual factors is also increasing through the adoption of literature from psychology (Estévez et al., 2015), but understanding and uptake of other factors might be lagging, such as cultural considerations and the influence of policy and governance. Therefore, this information may not be taken into consideration as much as other factors, and so more needs to be done to incorporate this. We suggest that further research in these areas is needed to fill this gap. Indeed, there is growing recognition that socio-economic and cultural factors and thus factors relating to perceptions are crucial for effective IAS management (Essl et al., 2017). Similarly, acknowledgment and work towards understanding uncertainty and complexity needs to be improved (Essl et al., 2017), which we highlight in this paper. Acknowledging complexity will ultimately improve understanding and help with decision-making. This links to improving stakeholder engagement and incorporation of different actors' perceptions with regards to decision making (Shackleton et al., 2019b). Furthermore, there are a few examples of how changes over time affect perceptions for well-studied IAS like prickly pear (Box 5), however, this understanding is still insufficient – especially research considering the socio-cultural underpinnings of changes in perceptions – and would be essential in future work.

Despite the growth of research in the field of invasion science, much of the research is still driven and conducted in the biological realm, with only 3% of studies incorporating social-ecological systems holistically (Vaz et al., 2017b; Abrahams et al., 2019). This points to the need for greater interdisciplinary and transdisciplinary (collaboration between different disciplines, different stakeholders/institutions and knowledge forms) work in the field, which will advance scientific understanding and make results more relevant for research, management and policy (Abrahams et al., 2019). Furthermore, it will be important to incorporate novel methodologies to better understand perceptions as well as how perceptions spread among individuals and groups. There are already useful approaches in other disciplines which could be adopted into invasion science, such as diffusion of innovations theory (Rodgers, 2010), network analysis (Borgatti et al., 2009; Prell et al., 2009), discourse analysis (Cottet et al., 2015), and multi-level perspectives (Udo et al., 2019).

There is increasing recognition that governance and policy development needs to be more inclusive and based on participatory processes and collaboration between different stakeholders and actors. This includes bringing in indigenous groups with different knowledges and perceptions and socio-cultural contexts which can help improve efficiency and build trust (Norgaard, 2007; Bhattacharyya and Larson, 2014; Humair et al., 2014b; Novoa et al., 2016; Crowley et al., 2017b; Shackleton et al., 2019a). We also highlight that there should be more in-depth research on each of the six factors individually to improve empirical understanding. Furthermore, studies are also required that cover all these factors to develop insights as to how they interlink and the complexity behind what sets of factors influence people's perceptions in specific situations and how they change with time (Woodford et al., 2016). The framework is a first, integrated step which will benefit research and management though enabling a more holistic understanding of what influences people's perceptions and how this might influence future management.

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